Seasonal variation in diel activity patterns of Chinook salmon in the Sacramento-San Joaquin River Delta

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Abstract

We examined seasonal patterns in diel activity levels of juvenile Chinook salmon, *Oncorhynchus tshawytscha*, at multiple locations throughout the Sacramento-San Joaquin River Delta. Using midwater and Kodiak trawls, we compared diel patterns in catch per unit effort (CPUE) of salmon during spring and fall months. We found that CPUE was highest during the day in all spring sampling periods and highest at night during all fall sampling periods, consistent with activity patterns seen in other salmonid species. We discuss possible mechanisms driving these seasonal shifts in diel activity patterns, including differences between seasons in temperature, trawl type, fork length, and turbidity.

Introduction

The Delta Juvenile Fish Monitoring Program (DJFMP) has monitored populations of juvenile Chinook salmon, *Oncorhynchus tshawytscha* (Fig. 1), throughout the Sacramento-San Joaquin River Delta ("Delta") since the 1970s. A primary purpose of the monitoring program is to provide managers of Delta water operations with information on patterns in distribution and abundance of migrating juvenile Chinook salmon so that informed decisions can be made concerning water operations.

Until now, our efforts to determine Chinook salmon abundance have been conducted primarily during morning to mid-day hours with few exceptions. However, there is growing evidence that juveniles of other salmonid species exhibit complex diel patterns in activity levels: fish are primarily diurnal during spring and summer months but primarily nocturnal during fall and winter months (see Reebs 2002 for review).

Given these complex temporal patterns in activity level of other salmonid species, it is important to determine whether juvenile Chinook salmon exhibit similar diel activity patterns in the Delta.

The existence of complex diel activity patterns may have implications for the accuracy of our estimates of salmon abundance at different times of year. Therefore, the purpose of this study was to examine diel patterns in CPUE of juvenile Chinook salmon during spring and fall months at multiple sites within the Delta.

Methods

We conducted either Kodiak or midwater trawls at six sites during eight sample periods over the past 10 years (Fig. 2-3, Table 1). During each sample period, 10-20 minute trawls were conducted for >24 h on a near continuous basis. Water temperature and turbidity (during daytime trawls only) were also measured for each trawl.

All trawls were categorized as occurring in one of three times of day: (1) diurnal, (2) nocturnal, or (3) crepuscular, which we define as the periods either between first daylight and sunrise or between sunset and last daylight. CPUE (in fish/m^3) of each trawl was calculated as:

$$CPUE = \frac{\text{catch per tow}}{\text{net mouth area x distance sampled}}$$

To test for differences in CPUE among times of day for each site, we employed nonparametric ANOVAs. If significant differences were found, we used a Tukey-type non-parametric multiple comparisons test to determine which means were different.

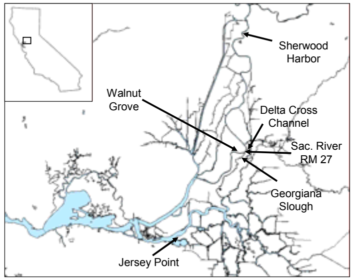

Figure 3. Map of sites in the San Joaquin-Sacramento River Delta.

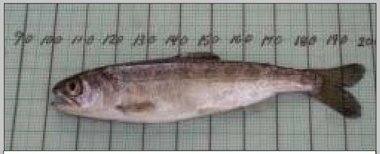

Figure 1. Juvenile Chinook salmon, *O. tshawytscha*, on measuring board.

Results

- CPUE of juvenile Chinook salmon varied significantly among times of day for all 8 sampling periods (ANOVA, $p < 0.001$ for each sampling period).
  - For every sampling period during spring, CPUE was greatest during diurnal and crepuscular hours (Tukey test, $p < 0.05$; Table 1, see Fig. 4A for example).
  - For both sampling periods during fall, CPUE was greatest during nocturnal and crepuscular hours (Tukey test, $P < 0.05$; see Fig. 4B for example).
- Mean fork length of targeted salmon was larger during late fall sampling than during spring sampling ($p < 0.001$).
- Mean water temperature was not significantly different between spring and fall sampling periods ($p = 0.96$).
- There were significantly more daylight hours in spring than in fall ($p < 0.0001$).
- Mean turbidity during spring sampling periods was significantly higher (i.e., Secchi readings were lower) than during fall sampling periods ($p < 0.0001$).

Figure 2. Trawl types used for sampling: (A) Midwater trawl, and (B) Kodiak trawl.

Table 1. Summary table for sampling periods in the study. Mean values (±1 SE) for fork length, water temperature, daylight hours, turbidity were calculated across an entire sample period. Asterisks in column titles indicate results of ANOVAs testing for differences between seasons. Tukey results are provided for all sampling periods because significant differences existed among times of day in all ($p < 0.001$).

Time of year	Study site	Dates	Tukey result for CPUE	Trawl type	Predominant race	Fork length (mm)*	Mean water temperature (C)	Mean daylight hours (h)**	Mean turbidity (m)**
Spring	Georgiana Slough[a]	4/29/96-5/2/96	(Day = Crepuscular) > Night	Kodiak	Fall-run	82.11 (0.14)	16.90 (0.12)	13:46 (0:01)	0.79 (0.01)
	Walnut Grove[a]	4/29/96-5/2/96	(Day=Crepuscular) > Night	Kodiak	Fall-run	80.90 (0.28)	16.76 (0.10)	13:46 (0:01)	0.80 (0.01)
	Jersey Point[a]	4/29/97-5/15/97	(Day=Crepuscular) > Night	Kodiak	Fall-run	84.19 (0.15)	17.97 (0.13)	13:58 (0:02)	0.58 (0.01)
	Sherwood Harbor	5/15/03-5/16/03	(Day=Crepuscular) > Night	Midwater	Fall-run	80.77 (0.47)	17.87 (0.03)	14:17[b]	0.52 (0.01)
		4/15/05-4/16/05	(Day=Crepuscular) > Night	Midwater	Fall-run	68.72 (0.92)	15.31 (0.04)	12:33[b]	0.75 (0.01)
		4/29/05-4/30/05	(Day=Crepuscular) > Night	Midwater	Fall-run	76.49 (0.81)	16.82 (0.04)	13:06[b]	0.97 (0.01)
Fall	Delta Cross Channel	10/29/01-11/1/01	(Night=Crepuscular) > Day	Midwater	Late fall-run	95.14 (2.35)	18.21 (0.03)	10:39 (0:02)	1.35 (0.01)
	Sacramento River, RM 27	10/29/01-11/1/01	(Night=Crepuscular) > Day	Midwater	Late fall-run	96.45 (0.54)	15.57 (0.02)	10:39 (0:02)	1.36 (0.01)

[a]Data collected by Hanson Environmental for DJFMP
[b]Total daylight hours
*$p < 0.001$, **$p < 0.0001$

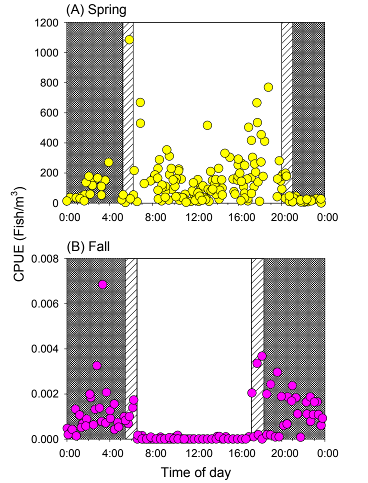

Figure 4. Examples of patterns in CPUE of Chinook salmon during sampling periods in (A) spring at Walnut Grove and (B) fall at the Delta Cross Channel. All other sampling periods yielded similar patterns. Shaded regions indicate nocturnal time of day, hatched regions indicate crepuscular hours, and white regions indicate daytime.

Discussion

We found opposing patterns in CPUE of juvenile Chinook salmon between spring and fall:

- CPUE in all spring surveys was consistently greatest during day and crepuscular hours and lowest at night,
- CPUE in both fall surveys was greatest during nocturnal and crepuscular hours and lowest during the day (Table 1).

This seasonal shift in diel patterns is consistent with seasonal shifts in diel activity levels of other juvenile salmonids in other studies (Sagar and Glova 1988, Ledgerwood et al. 1991, Fraser et al. 1993).

Many factors differed between spring and fall sampling periods that may have contributed to this shift between seasons in diel patterns of CPUE (Table 2). The actual cause of these patterns likely involves a combination of one or more of these hypotheses and others not discussed.

Determining the mechanisms driving seasonal changes in diel patterns of CPUE of Chinook salmon is important for the DJFMP because it would allow us to adjust timing of our sampling to obtain the best estimate of actual salmon abundance. At present, we generally sample only during morning and midday hours throughout the year. As a result, we may be underestimating fish abundances during times of year when fish are predominantly nocturnal and overestimating fish abundances during times of year when fish are predominantly diurnal.

Table 2. Potential mechanisms driving seasonal shifts in diel patterns of CPUE of juvenile salmonids.

Variable	Mechanism	Our study
Temperature	A temperature-dependent shift in activity level involves a trade-off between foraging efficiency and predation risk (Fraser et al. 1993). When temperatures decrease, the metabolism of fish is reduced. Lower metabolism reduces mobility, increasing the risk of predation by endothermic predators (e.g., birds and mammals). However, lower metabolism also reduces energy requirements. Therefore, fish can "afford" to forage during nocturnal hours when foraging efficiency is lower. In warmer conditions, fish metabolism is higher and, thus, energy requirements are higher. As a result, salmon must forage during the day when their foraging efficiency is greater, despite higher predation risk.	Temperature varied much more among sampling periods within season than among seasons. Therefore, this hypothesis is not supported by our data. To confirm the rejection of this hypothesis, we recommend sampling at a single site under different temperature regimes, but with as similar physical conditions as possible.
Trawl type	A Kodiak trawl employs two boats that herd fish into the net, whereas a midwater trawl uses one boat. Further, the Kodiak trawl net is larger and its mesh size is smaller than midwater trawls.	Both trawl types were conducted in spring, yet yielded identical diel patterns in catch. Therefore, this hypothesis is not supported by our data. To confirm the rejection of this hypothesis, we recommend conducting side-by-side sampling of both trawl types over 24 hour periods at multiple times of year.
Fork length	Larger fish tend to be less active, possibly because digestive rates are lower for larger fish, and, therefore, may not need to forage during the day. Also, larger fish may physically be able to avoid the trawl net more easily than smaller fish because they are stronger swimmers. Therefore, counts of larger fish should be lower during the day when the net is visible.	Larger salmon were present during fall sampling. These fish were caught predominantly at night, as predicted. Therefore, our data support this hypothesis. To further investigate this hypothesis, we recommend analyzing patterns in CPUE of different size classes of salmon caught simultaneously.
Turbidity	Net avoidance by fish should be more difficult when turbidity is greater (i.e., visibility is lower). However, because light levels have little influence on the reactive distance of fishes in highly turbid waters (Benfield and Minello 1996), this difficulty in net avoidance, and, thus, CPUE, should not vary significantly throughout a 24 h cycle in high turbidity conditions	Turbidity was significantly greater during spring sampling periods, yet CPUE varied among times of day. Therefore, this hypothesis is not supported by our data. To confirm the rejection of this hypothesis, we recommend monitoring on a 24 hour period at even greater turbidity levels than those found in our study.

References

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